of 70 per cent in preference to a grid-modulated amplifier with an efficiency of only about 30 per cent simply because they did not know how to produce, with reasonable efficiency, the high-power voice-frequency supply necessary to feed the modulated amplifier. If it had only been necessary to modulate with a single frequency, such as could be obtained with good efficiency from an alternator, there would never have been a case for employing low-power modulation.

It appears, however, that the situation is now changing, and with the advent of vastly improved high-power speech-frequency transformers the programme can be raised to high power with good efficiency by means of Class B push-pull low-frequency amplifiers; and so under the new circumstances greatly improved overall efficiency can be realized by using a Class B push-pull low-frequency amplifier to modulate on the plate of a final high-frequency stage. Mr. Ditcham considers that the harmonic content in this case would be very high, but I think he is taking an over-pessimistic view in this respect.

The authors express the opinion, but with some reservation, that the particular type of plate modulation which they have adopted, namely series modulation, is advantageous from the point of view of quality of reproduction, particularly in regard to transient waveforms, owing to the absence of iron-cored speech-frequency chokes or transformers. There is, however, another school of thought which holds that the use of speech-frequency transformers—even at high power—is not inconsistent with the attainment of the accepted standards of broadcasting quality. The matter would appear to hinge around leakage reactance, and it should be viewed with due regard to the very low values of leakage reactance expressed as a percentage of the open-circuit primary inductance obtainable in the most modern transformers.

Turning to another point, the value of the capacitance in the high-tension smoothing circuit is smaller than one might have thought necessary on a basis of computation to ensure low harmonic content, but the results justify the value chosen. I should like, however, to ask the authors what harmonic content and phase distortion they estimate must be introduced by the impedance of the smoothing condenser at the lower audio frequencies, together with its series resistance.

Turning to the statement in the paper to the effect that the harmonic content for 90 per cent modulation is 4·3 per cent, I note that the fundamental audio frequency is not mentioned. It would be interesting to know over what band of audio frequencies this value holds good.

Mr. M. Shams-el-Deen: I should like to ask a few questions regarding the method of modulation adopted for the long-wave transmitter, known as "series modulation." Although I appreciate the careful experimental work which has been done by Marconi's Wireless Telegraph Co. on the problem of how to avert serious side-band cut-off without employing a complicated design which may require critical adjustment, I cannot understand why, if they aimed at faithful reproduction at the loud-speaker end of what is taking place in the studio, the B.B.C. did not use the "phase modulation" system installed by the Société Française Radio-Electrique at the Poste Parisien broadcasting station. Are the authors aware that the efficiency of the last circuit in that system is about 66 per cent, while that in the plant which we are now discussing is only about 32 per cent? Did the authors ever contemplate introducing this method into this country and, if not, why not? Looking at it from the engineering point of view, is it not far superior to the series modulation system in every respect?

Dr. L. E. C. Hughes: With regard to a level frequency/response characteristic for the side-frequencies in the antenna current, could not equalization be more easily effected in the low-frequency circuit, and so save the power loss in the line filter? In practice, the energy distribution among speech and music frequencies falls off very considerably in the higher parts of the transmitted band, and so no overloading may be feared when the levels of the upper frequencies are raised before modulation. I cannot see that it is very important for the output and antenna circuit to have a level frequency/response characteristic, provided the frequency/response characteristic of the whole system is level.

With regard to high percentage linear modulation, this can be readily obtained by modulating to a degree which is linear and increasing the percentage modulation by injecting the carrier in anti-phase in the output of the modulator. In this way Reeves* removed the carrier altogether.

Mr. J. A. Gracie: The authors state that the master-oscillator drive circuit was designed partly with a view to possible changes in the station frequency due to international arrangements. Perhaps they would state what alterations to the transducer system would be necessary in the event of a change of transmitted frequency. Perhaps, too, they could give some information regarding the amount of power lost in the transducer circuits.

Mr. P. G. A. H. Voigt: I notice that the published response curve stops at 6 000 cycles per sec. I should be interested to know whether there is any information available as to what happens above that frequency.

[The authors' reply to this discussion will be found on page 485.]

South Midland Centre, at Birmingham, 11th March, 1935.

Mr. D. R. Parsons: I should like to ask a question regarding the low-frequency characteristics of the National transmitter. Previously, the B.B.C. has used Heising or choke modulation, which tends to give a falling frequency/response characteristic to the transmitter, owing to the iron present. With series modulation, however, I presume it is quite possible to obtain a rising characteristic.

In view of the fact that receivers are far more distortionless than they used to be, would it not be desirable to raise the level of the higher audible frequencies and

* A. H. Reeves: *Journal I.E.E.*, 1933, vol. 73, p. 245.

so obtain at the transmitting end the tone correction required by modern low-decrement high-frequency circuits? I should like to know the opinion of the B.B.C. on this point.

Mr. R. K. Hartley: As regards the quality of tone in the transmissions from the Droitwich stations, I think it is a great improvement on that of the old Daventry station. The quality of the reception from the B.B.C. stations is the finest I have heard.

Mr. H. S. Dransfield: I should like to hear more with regard to the causes of the fading of the Droitwich long-wave transmitter, which has aroused interest in many parts of the country. I would also ask why the quality of the transmissions varies so widely.

When inspecting the station I noticed that the reading of the modulation ammeter was varying over wide limits; it would be interesting to know the factors that are taken into consideration in determining the amount of modulation at any particular time.

I note that the operator who listens in at the station exercises control, and I should like to know on what lines this control is arranged.

Mr. H. Hooper: I should like to know why a private power supply was installed at Droitwich. The station has four 470-kW sets running at about 78 per cent load, and taking into account the price of fuel oil delivered at Droitwich I should say that, assuming one spare set, i.e. three sets in more or less continuous operation, the cost would be not less than 0·5d. per unit, and probably nearer 0·52d. per unit. On the other hand I assume that the authors could have got a price per unit of 0·5d. delivered from a reliable source or multiple sources. It appears to me that the question of cost did not enter into the question of a private versus public supply.

Mr. C. F. Partridge: Was the mechanical strength of the material when subjected to high-frequency electrical stress used as a basis for the mechanical design of the mast supporting insulators? Why was it decided not to use grid control for running up the voltage on the mercury-arc rectifiers? In estimating a satisfactory field strength of 2·5 millivolts per metre, what type of receiving apparatus is assumed? With regard to the variation in frequency, how is this quantity so accurately measured? Why is it necessary to have such comparatively long lengths of water-filled tubing leading to the transmitting valves?

Mr. R. H. Rawll: The point that impressed me most on inspecting the station was the extraordinary efforts which had been made to duplicate the pieces of apparatus which experience had shown would probably be liable to fail, and the methods adopted to effect the change-over in the minimum of time. The supply engineer has to face a similar problem, but on a limited scale. There is a distinct difference, of course, between supply work and broadcast work, inasmuch as a distribution organization feeding a town or city has only a proportion of its consumers affected should the supply fail in a particular area of the network, whereas the results of a failure of the transmitting service of the B.B.C. are felt by several millions of listeners. I presume there is a certain time-lag between the time of the failure and the switching-in of the duplicate piece of apparatus, which accounts for the term "technical hitch" utilized by the B.B.C. when apologizing for a break in the transmission.

I should like to know the voltage which is induced in the stay-wires of the aerial masts. I believe a very high voltage is induced in the stay-wires at the G.P.O. station at Rugby, and on one occasion a serious accident resulted from a person making contact with a stay-wire at the anchorage insulators. Are any particular precautions taken at the Droitwich station on this account?

Mr. H. Faulkner: The paper has brought back to me recollections of the many problems with which we were dealing some 9 or 10 years ago in the design of the Rugby radio station. I am pleased to note that many of the conclusions which we came to at that time are still regarded as sufficiently good for modern practice; I am equally pleased to see that many very remarkable improvements have taken place, notably in the lay-out and design of the station. The authors were able to produce the necessary output, which, bearing in mind the modulation requirements, calls for about the same valve provision as at Rugby, with only four valves. This shows the very remarkable progress which has been made by our valve manufacturers in designing valves for wireless transmission purposes. Coming to rather smaller details, on page 441 I notice that one of the requirements was that "the Post Office buried cable circuits must be available within 3 or 4 miles of the site." I should have thought that it would have been possible to allow of much greater distances than that, seeing that it would not have been necessary to take more than a few pairs into the station. I notice that the authors have adopted the method of supplying cooling water through hose-pipes. This is a departure from the original B.B.C. practice at Daventry, in which a sprinkler was used; I have a suspicion that the sprinkler was not altogether successful, and I should like some information on that point. The use of Electroflo meters is to my mind very sound practice. The authors state that a very constant voltage is essential for the purpose of supplying the protective circuits; I cannot see why this should be so. I imagine that what the authors really mean is that the voltage should be always there, rather than constant in magnitude.

Regarding the half-wave aerial for the medium-wave station, I should be very interested to know what increase in service area has been obtained by this means. These aerials were used originally in Germany with a view to giving less radiation in an upward direction and a bigger radiation along the ground, so extending the distance from the station of the point of fading.

The method used on the mercury-arc plant for suppressing flash-arcs is very ingenious and gives a great advantage for anode supply to large transmitting valves. I am interested to see that small condensers are connected between the grids and filaments of the large valves. This feature was introduced first of all into the Rugby transmitter, and was always found to be satisfactory.

The brilliant work on the output circuit is the outstanding feature of the station, and gives to Droitwich a very definite superiority over all other long-wave broadcasting transmitters. The series-modulation system seems to be a very distinct advance.

Mr. P. N. Murdoch: The decision taken by the B.B.C. in favour of a private power supply was presumably based on considerations either of cost or of reliability. Mr. Hooper has dealt with the question of cost fairly satisfactorily, and I should like to mention reliability. As I am directly connected with the supply company affected, and responsible for the continuity of supply in that area, I should like to say that there is a duplicate 66-kV line passing quite close to the Droitwich station, and we could have given a reliable supply to the station without any difficulty. Further, there has not been a breakdown on that line for over 12 months.

Mr. H. H. Taylour: I should be interested to know what troubles, if any, have been experienced with the two independent systems of high-tension d.c. supply during the admittedly short period of operation so far completed. An installation of this description, using mercury-arc rectifiers and generators under practically identical conditions, should enable a direct comparison to be made between the merits and demerits of the respective systems.

With regard to the transmitters proper, what substantial advantage is gained by employing the somewhat elaborate aerial transmission lines and transformer houses in preference to the simpler and, one would imagine, more economical arrangement of feeding the aerial direct from the main transmitter building?

Mr. C. R. Woodward: There is ample evidence at Droitwich of the tremendous strides that the B.B.C. have made in transmitter design and technique since the days of the experimental station at Daventry.

It is interesting to note that their H.T. supply has changed from thermionic valves to mercury-arc rectifiers and high-voltage d.c. generators. I remember that Daventry 5GB had a 10 000-volt d.c. generator that could not be relied upon. The change to a closed-circuit cooling system seems to me to be a logical step.

The initial drive of the National transmitter is in substance only a plain *LC* circuit, for which the authors claim a frequency stability of 10 parts in a million, which is indicative of very good design; is the Regional transmitter controlled in the same way? It has been my experience that it is much more difficult to maintain frequency stability on the lower wavelengths without resorting to mechanical resonators or piezo-electric control.

The reflector of the medium-wave aerial is a new departure, and while it is not unusual to use a reflector on short waves I am doubtful of its efficiency on the medium wave-band. It would be of interest if the authors could include in their reply a polar diagram showing the field-strength distribution due to this aerial.

Mr. R. E. Coomber: I remember that about 12 years ago, in the early days of broadcasting, the power employed was about 1 kW, and apparently such stations as Bournemouth, London, Aberdeen, etc., were received quite well in the Midlands with this low power and with the comparatively inefficient receiving sets of that period. Since then the stations have progressively increased in power from 1 kW to 150 kW, and the service areas, apart from that of the National transmitter, are apparently the same. Under present conditions it is impossible to receive 1-kW stations at anything approaching the same distance from the transmitter as formerly—even with modern sensitive receivers. Is this diminution of transmitting range brought about by the swamping effect of the powerful stations interacting and cutting down the effective range? If so, would it not be possible by a reduction in strength of both English and foreign transmitters to give the same service area and efficiency?

Mr. F. C. Orchard (*communicated*): I should like to know whether the opinion expressed at the bottom of page 444 and the top of page 445 relating to the inferiority of mercury-arc rectifiers as compared with high-tension motor-generator sets is based on B.B.C. experience at Droitwich. If so, what factors contributed to that view being taken? If not, it would appear unfair to British manufacturers to class them with unsuccessful makers on the Continent.

If the motor-generators are operated in series how does the output wave-form compare at light and full loads with that of the rectifier equipment using a smoothing circuit? It is a pity that a timing wave was not recorded on the oscillograms shown in Figs. 12 and 13, and that a scale of values of current and voltage is not shown. These oscillograms are reduced to the level of pictorial illustrations, without the means of checking up values.

Referring to the protection of the motor-generators at times of flash-arc or heavy d.c. overload, an oscillogram comparable with Figs. 12 and 13 would have added much in interest to the paper. Furthermore, one has to read the last paragraph on the left of page 452 most carefully if one is not to draw an unfavourable comparison with the rectifier operating under similar conditions. In the one case the short-circuit is cleared in 1 or 2 cycles, while in the other the most that is done is to reduce the actual fault current to zero and substitute a short-circuit current limited by the inherent characteristics of the machine and choke. How long this condition persists is not stated. What means are used to shut down the motor-generator sets when running on artificial short-circuit? Is this system of protection used when machines are operating singly and not in series? It would appear that the shock to the generator is most severe during the time the flash-arc occurs and the artificial short-circuit is applied. It would be of further interest to know how many power-plant generators were on the busbars during the test and what was the extent of the frequency deviation. For how long was the disturbance manifest before the standard frequency was regained? Because of the severity of such short-circuits and the fact that a common power plant supplies two transmitter systems, it is somewhat surprising that the B.B.C. decided on a comparatively small private generating station. Would not the service have been less affected by having the large amount of synchronizing power which would have been behind the service lines of a local authority's system? An oscillograph record of the voltage, current, and frequency, at the generating-plant busbars at such times of short-circuit supply with two, three, or four generators in commission would have been very illuminating.

[The authors' reply to this discussion will be found on page 485.]

North-Western Centre, at Manchester, 2nd April, 1935.

Mr. T. E. Herbert: The point is made in the paper that the quality of the output is very largely dependent on the telephone connecting links between the studio and the station. It is, of course, a fact that in the use of ordinary telephone cables there are rather serious limitations as regards cut-off. In the cables employed, special circuits have been treated for the use of the B.B.C., but I foresee the day when greater fidelity will be required and the type of circuit at present provided will no longer be adequate for the purpose. There is no difficulty, other than that of cost, in providing telephone circuits which will transmit a very much higher range of frequencies than is required. For example, there is the coaxial telephone cable which is in process of development and by which an enormous band of frequencies can be transmitted. Indeed, by means of this type of cable 200 separate channels of speech can be provided on a single core. When greater fidelity is required, broadcasting will go through the same stages of development as the gramophone went through.

Will the authors tell us whether they have yet contemplated the use of the demountable valve which was recently developed in Manchester, and which gives an output of something like 500 kW?

Mr. G. F. Sills: I have had the privilege of visiting the North Regional Station at Moorside Edge, and one of the things that I remember is that arrangements have been made to enable a current of 300 amperes to be put into the aerial with the idea of melting any snow or ice. Is this provision necessitated by the height and location of the site, and is the same procedure necessary at Droitwich?

One of the authors' slides showed a transformer house near the aerial, and lightning arrestors were in use. It would be interesting to know what the air-gap is set at to achieve the desired purpose.

Mr. F. Roberts: With reference to the series-modulated amplifier, I should like to know the actual value of the total capacitance to earth from the filament-heating generator and its associated equipment, including the grid-biasing device. On the occasion of last year's visit of the Wireless Section to Droitwich, I was told that this capacitance was of the order of 100 $\mu\mu$F. Since the capacitance between two concentric spheres of radii $0 \cdot 5$ and 1 metre respectively, to which the generator and surrounding earthed objects roughly correspond, is approximately 100 $\mu\mu$F, this figure appears to be very small for the total capacitance referred to in my question.

I should also like to know whether the bald statement that distilled water is used for cooling the anodes may be taken as implying that distilled water is a perfectly satisfactory cooling agent, and that no troubles are encountered in its use.

Mr. F. W. Taylor: The authors describe at length the apparatus and working of the various sections of a modern broadcasting station. It occurs to me that however important these parts may be they could not function at all without the connections between sections and between the component parts of one section. As a large portion of the apparatus involves high d.c. potentials, and in view of the serious effect of breakdown, it would be interesting to have some information on how far it is preferable to use bare h.t. connections and how far to use insulated cables. Also, in view of the special nature of dielectric phenomena under d.c. conditions, I should like to know whether the authors have experienced any difficulty due to sealing-end troubles or the accumulation of dust, which always occurs when a point is maintained at a high negative potential with respect to earth.

Mr. F. Jones: Referring to the descriptions of the master-oscillator units, the designers have apparently decided in favour of this method of control as against a crystal-controlled drive. The master-oscillator method has the undoubted advantage of permitting a rapid change of transmitted frequency, and the frequency stability mentioned—10 parts in a million—compares very favourably with that obtainable with a crystal drive. The precautions required to maintain this accuracy, however, appear somewhat elaborate and a great deal depends on the particular valve in use. The necessity for maintaining the valve filament continuously heated might be expected to lead to frequent replacement of the oscillator valve, involving difficult frequency adjustments with each new valve.

An interesting point which arises in connection with the speech-input arrangements is the relation between the variations in volume of the programme being transmitted and the corresponding variation in amplitude which can safely be applied to the transmitter, and the means of controlling this input. Experience in the reception of, say, an orchestral programme, indicates that the manual control, which is presumably employed, sometimes give rise to irregularities in the volume received, on account of the obvious difficulty of following, by hand, the variations of volume encountered. It would therefore appear that some form of automatic gain control would be desirable, and perhaps the authors could say whether such a method has been considered.

Mr. W. Fennell: I feel that perhaps in 10 years' time the number of units of generating plant of various kinds will be rationalized, and there will be three or four, just as in a power station. Some means may be found of simplifying the plant so that it will not cost so much. The B.B.C. apparently are very keen on costs, especially in regard to the generation of power.

I sympathize with the authors in the difficulties they have encountered owing to the site being in a salt area. In Northwich we also have trouble from subsidence due to the existence of brine pumping. I note that the paper refers to "an extensive subterranean brine stream, which flows for several miles through the district which is otherwise the most suitable"; I should like to know where that stream rises, and where it runs into the sea. The authors must mean that as there is brine pumping in Droitwich, and as subsidence follows brine pumping, they had to take care they did not put the station where there is rock salt.

One point of national importance, in my opinion, is in regard to power plant and power generation. The authors put forward very weak arguments why the B.B.C. should not patronize another big corporation of a semi-Government type, namely the Central Electricity

Board. They say that reliability is of great importance and that they must not depend upon anybody else. This means that they must have a power station of their own, quite detached, and very unkindly they say that it is probably cheaper than buying the energy from the national supply. They might at least have adopted the alternative scheme of taking half the energy from the public supply and the other half from their stand-by plant. I do not accept their figures as to cost, because I happen to have been responsible for the running of Diesel engines and know that actual costs often greatly exceed estimates. Taking Mr. Kennedy's figures* for 50 per cent load factor, which is about what the station will run at (roughly 12 hours per day), the oil-engine all-in cost comes out at about 0·7d. per unit; allowing 10 per cent loss, the grid price is 0·4d., and adding to this sum a profit equal to one-third of that prime cost, we get a competitive figure of 0·53d. In the paper referred to, Mr. Kennedy proved that—by reason of the very low grid unit price of 0·2d. per unit—the higher the load factor the bigger the advantage of buying from the grid.

I should like to know how much the power station cost, and the annual cost of running it. In other words, how much per kWh does it cost to run the plant, and what is the load factor? It may be that these figures will justify what the B.B.C. have done, but at present I suggest that they have not proved their case.

With regard to the general policy of having an independent plant, because of the presumed importance of B.B.C. broadcasts, failures are not unknown. We do not know how many are due to power plant, but I suggest that very few would be due to failure of the public supply. Normally, however, very great reliability is not required from any one station of the B.B.C. Even if Droitwich did fail, the public could quickly tune in to another B.B.C. station.

Mr. G. G. L. Preece: It would be interesting if the authors could let us know what is the practice of some of the foreign stations, say in Germany, in regard to power supply. Do they have their own power plant, or do they take the power from their "grids"?

With regard to the use of mercury-arc rectifiers with grid control, this does increase the ripple effect quite a lot, and it would be interesting to know whether any special smoothing device is employed in connection with this which stops any ill-effect on the transmitter.

Mr. A. H. Gray: I notice that two of the CAT valves are housed in each cubicle, the third being only brought into action in the event of a breakdown. Bearing in mind the care with which these valves are transported and housed, it would appear that some considerable time must elapse before a valve can be fitted, and a further delay must occur whilst the filament is brought up to the correct working temperature.

Have the authors any particular scheme whereby this time can be materially reduced, and furthermore what is the order of this delay?

[The authors' reply to this discussion will be found on page 485.]

North-Eastern Centre, at Newcastle, 8th April, 1935.

Mr. F. G. C. Baldwin: The paper indicates the remarkable advances which have taken place in the art and science of broadcasting since its inception. It also shows that the present-day communication engineer has to deal with power units of no small size.

In the early days of broadcasting, studios were situated in close proximity to the broadcasting transmitters; modern conditions have necessitated that studios should be placed more conveniently for artists, and transmitters situated in positions ideal for their purpose. This has been rendered feasible by the utilization of circuits in underground cables provided and maintained by the Post Office Engineering Department, and there is a considerable network of such circuits now in use by the British Broadcasting Corporation.

Long-distance telephonic communication exclusively over underground cables has developed in a remarkable way along with the development of broadcasting, and has assisted greatly in the satisfactory distribution of programmes and in ensuring their reliability. The use of underground-cable circuits for broadcasting has necessitated the provision of telephone lines superior to those customarily used for speech, i.e. lines which will transmit the greater range of frequencies required for the satisfactory reproduction of music and other sounds. In addition to these lines provided exclusively for the British Broadcasting Corporation the Post Office system of communication is in constant use for various broadcasting purposes, and there is active co-operation between the B.B.C. engineers and the Post Office engineers.

On page 442 the authors say that to generate power locally is as cheap as, if not cheaper than, to buy from the public supply mains. I should like to know what is the factor which makes this so. Is it the remoteness of the transmitting station from the electric supply mains, and the cost of the power transmission line?

The authors mention that mercury-arc rectifiers, although not so reliable as motor-generators, are employed for the high-tension supply, largely, I suppose, because of their higher efficiency. I gather that they were installed more or less experimentally, and it would be interesting to know whether the decision to employ mercury-arc rectifiers has been justified in practice and whether any breakdown has occurred or any particular difficulty been encountered.

On page 460, certain smoothing arrangements are indicated which appear to me somewhat inadequate, and I should be glad if the authors would say whether these are the only precautions found necessary to prevent ripple.

The low field strength at Newcastle is mentioned on page 468, and a possible reason is assigned for it. When the Droitwich long-wave station was first opened we in this locality suffered considerably from fading and distortion. Although the trouble still occurs it has largely disappeared, and it would be interesting if the authors would tell us whether the improvement observed may be attributed to natural causes or

* *Electrical Supervisor*, 1934, vol. 14, p. 178, diagram No. 9.

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* *Electrical Supervisor*, 1934, vol. 14, p. 178, diagram No. 9.

whether it is due to improvements introduced at the transmitter.

Mr. William F. Smith: The authors may have felt some trepidation in accepting the invitation to read their paper before this Centre, situated in a city that can boast of a field strength from Droitwich of only 6 millivolts per metre. It must be remembered, however, that they were set the colossal task of satisfying some 15 to 20 million listeners located in dense groups a considerable distance apart. When the question is viewed from this angle it must be appreciated that considerable success has resulted from their efforts.

The authors rather infer that the band width of the B.B.C. transmitter is limited by the poor response of the Post Office lines connecting the studio and transmitter. The P.O. lines are capable of satisfactorily transmitting up to 7 000 cycles per sec., representing 14 kilocycles per sec. in the ether after the modulation stage has been passed. International agreement limits the separation between stations to 9 kilocycles per sec., and therefore the transmission of any band greater than 9 kilocycles should not be necessary. The transmission of a wider band may, of course, be desirable for listeners near the transmitting station, but considerable interference is likely to result for listeners not so favourably situated, owing to overlapping wavebands.

I do not agree that a considerable amount of fading can occur without the average listener being aware of the fact. He may not recognize the phenomenon as fading, but the reduction of signal/noise ratio which results from fading causes a change of listening conditions which cannot fail to be observed. Sets fitted with automatic volume control are not immune from this trouble if the normal signal/noise ratio is low.

It would have been useful if the paper had included a field-strength polar diagram under night conditions, for comparison with the daylight diagram, in order to indicate the relative fading in various directions.

The fading on Droitwich which was experienced in this area on the opening of the station, appeared to be of a selective character, and perhaps the authors can say whether their experience is that selective fading is very pronounced. My experience has been that the fading of the Droitwich transmissions has been very much reduced during the past 2 months.

The provision of a filament-heating generator for each water-cooled valve in the long-wave transmitter seems a costly and unnecessary elaboration. The isolation of the spare valves could be easily and quickly performed by means of isolating switches. There would appear to be no gain in regard to "continuity of service" resulting from the provision of the extra machines.

The principle of providing plant, including spares, of such a character that flexibility to suit all eventualities is attained, seems to have been departed from in the provision of high-tension supplies for the medium-wave-transmitters. The two 12 000-volt machines for this purpose were specially designed and constructed with insulated cores, and must have been very costly. Would it not have been better from the point of view of flexibility, and possibly cheapness, to use, say, four 6 000-volt machines connected in series as required? In an emergency, when these machines were in use for the long-wave transmitter three of them in series would probably suffice (on a reduced power output), thus leaving one machine as a stand-by.

The insulation of the machines from earth as a whole would appear to be an easier proposition than insulating the core from the shaft, and perhaps the authors will say what were the reasons which led to the adoption of the higher-voltage type of motor-generator.

It is interesting to find that in these days of rapid development of radio valves, a place can still be found for a valve which must have been developed some 15 or more years ago. I refer to the LS5 valve employed in the master-oscillator stage. The "life" of these valves is remarkable; I know of a case where one of these valves exhibited characteristics almost as good as new after 4 years' use for 20 hours per day.

The type of volume indicator on the speech-input circuit is interesting. Why is the standard of volume termed "zero volume"? The more usual term is "reference volume." Presumably the method of operation of the meter is that it integrates a voltage between some fixed voltage value and the peak voltage. Can the authors give the approximate period over which such integration takes place, and say how the fixed value (which presumably does not operate the meter) is decided upon. What percentage modulation does this figure represent?

It is observed that the equalizer is placed directly in the Post Office line without the intervention of a line amplifier. The level of the programme at the control potentiometer is of the order of 16 decibels below zero volume, and it would seem that cross-talk and power hum are likely to be picked up on the gain control.

The method of lighting the masts and at the same time retaining insulation from earth as far as high frequencies are concerned is interesting, but I do not see the necessity for the centre pair of coils between earth and the mast structure.

What is the "make-up" necessary in the distilled-water circulating system? I should like to conclude with just one other question: What is an "average" receiver?

Mr. H. V. Field: The authors state that the reliability of high-voltage mercury-arc rectifiers is, at the present stage of development, inferior to that of motor-generators. What are the troubles that have been experienced in Continental stations using such rectifiers? Does the experience gained at Droitwich up to the present confirm the above statement?

Induction-regulator control of voltage on these rectifiers is preferred to grid control, although the latter is simpler, cheaper, and able to cover the same range. The wave-form on the output side deteriorates with reduction of voltage when grid control is used, and a greater degree of smoothing is required than would be necessary with induction-regulator control. Is this the reason for the selection of the first method?

The master oscillator is designed for 100 kilocycles per sec. and frequency-doubling is employed to give the required 200. Why is this method preferred to direct operation of the oscillator at 200 kilocycles per sec.?

The earthing system would appear to operate as much as a counterpoise as an earth. The size of the earth

wire (No. 16 S.W.G.) seems rather small. What determines the wire size employed, and is it a compromise between surface area and high-frequency resistance? Have any difficulties been experienced resulting from corrosion on these small wires?

The 150-kW valves are presumably of the directly heated type. What type of filament is used? Have indirectly heated cathodes been developed for such work? These would permit the use of a higher voltage for the heater, which would be preferable for both construction and operation.

In some Continental systems the mast has been used as a vertical aerial. How do the characteristics of such a system compare with those of normal types of aerials such as are used at Droitwich?

The conversion efficiency of the final stages of the transmitter only reaches 33 per cent. Methods are being developed, using constant modulation depth and variable carrier amplitude, which give a much higher efficiency. Are such schemes satisfactory in practical operation?

Captain F. W. Gaskins: I should like to ask whether any serious trouble has been experienced due to low insulation of the aerials. No doubt tests are made from time to time, and it would be interesting to know within what limits the insulation resistance varies. What is the lowest figure for satisfactory working, and is it found that an extremely high figure—if this is ever obtained—produces any better results than a moderately high one?

It would be interesting to know how the masts stand the climatic conditions. Are they treated both at the works before dispatch and also after erection, and, if so, what with? How long is it before they have to be treated again?

With regard to fading, those speakers who have mentioned that they do not notice any trouble of this sort must employ receivers equipped with all the latest improvements, and reside where these effects are not noticeable (if this is possible). I notice both fading and distortion of the Droitwich programmes, and many of my friends report similarly.

Mr. A. G. McDonald (*communicated*): On page 439 the authors state that the service frequently becomes unacceptable on account of fading during the hours of darkness. Surely service-area, as distinct from long-distance, reception is largely governed by the angle of propagation of the radiation. If a high-angle radiation is used fading will be severe at distances where this radiation reflected downwards becomes out of phase with the horizontally projected wave. The angle of radiation has been investigated and controlled in the case of short-wave aerial systems, e.g. beam antennæ, but the problem of providing low-angle radiation on long-wave aerials has only recently received attention. It is known that various Continental stations have been experimenting with special aerials intended to give this type of radiation, and perhaps the authors would say whether they have any knowledge of these experiments.

On page 447 the method of laying the earth connection by the use of a plough is described. This method was first used at Leafield radio station, and a development of this system has resulted in the laying of multi-core telephone cables by a mole drainer. What is virtually a furrow is cut, the cable is drawn in, and then the sods are turned back.

The B.B.C. have found that the h.t. motor-generator is very reliable. The Post Office also have experienced trouble-free service from the 18 000-volt d.c. motor-generators at Rugby radio station. Except on the score of efficiency there is little to be gained by the adoption of mercury-arc rectifiers.

It is rather surprising to find that the B.B.C. rely on a master oscillator in these days of piezo-electric crystal and tuning-fork drives. Presumably a control within 1 part in 100 000 is good enough for the service required, and quick changes of wavelength may be required.

I note that distilled water contained in a copper-pipe system is used for the cooling of anodes and filament seals of transmitter valves. Is it too early yet to say whether any noticeable erosion has occurred? At Rugby radio station pure distilled water had such a solvent action on iron pipes that many lengths had to be renewed, and some tons of sludge had to be removed from the tank. Rain water was afterwards used in place of distilled water as being sufficiently pure while at the same time being less active chemically.

One of the most interesting statements in the paper is contained on page 467, where the authors say that in early tests of this type the effective height of the aerial was measured and the measured value was found to give incorrect results. In view of the fundamental importance of experiments of this character, on which relatively little information has been published, I suggest that the authors might be asked to give the results of their experiments in amplified form in an additional appendix. Perhaps the authors would say what was the method of measuring the effective height. If it was measured by the usual method of transmitting energy from the aerial and then measuring the field strength at a number of points situated some distance outside of the range of the inductive field, then it would seem that if by so doing incorrect results were obtained the whole basis of the known laws of radio energy propagation require modification.

[The authors' reply to this discussion will be found on page 485.]

SCOTTISH CENTRE, AT GLASGOW, 9TH APRIL, 1935.

Prof. G. W. O. Howe: In the oscillogram of Fig. 6 (Plate 1), which purports to show the excellence of the wave-form of the alternator, it looks as if a high harmonic were superimposed on the wave. Is this really a harmonic? As the frequency appears to be about 2 000 cycles per sec. I suspect that it is really due to a faulty oscillograph.

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aspects of the problems that arise in connection with any application of the arc rectifier.

Turning to Fig. 25, I suppose that the only variables here are really the frequency and the resistance, and I presume that from the curve one could calculate the inductance and capacitance of the aerial.

There is an uncomfortable air of compression about the paper. In particular, I think that if the Appendix were made twice as long, it might thereby be made ten times more intelligible and interesting. A similar remark applies to the explanation of Fig. 27. In Fig. 26, for example, there are many cases of two condensers connected in series, such as C_{21}, C_{22}, etc. In Fig. 27 they are replaced by condensers of $2C_{21}$, $2C_{22}$, etc., and not, as one might expect, by condensers of $0 \cdot 5C_{21}$, $0 \cdot 5C_{22}$, etc.;* but no reason appears to be given for this. One is left to infer that Fig. 27 represents the two sides of Fig. 26 connected together in parallel, the earth forming the other terminal, in which case it is to be hoped that the values of L_{11}, etc., have also been suitably modified.

Mr. J. Greig: I should like to ask one or two questions in regard to the high-frequency output stage of the transmitter. As the use of two CAT14 valves in each side of the push-pull circuit in place of a much larger number of CAT6 valves in parallel represents a fairly drastic change in practice, it would be interesting to know whether the tuning-up troubles due to instability and parasitic oscillations were materially different from those usually encountered with the older arrangement. I understand that valves of the CAT14 type, when run singly under works test conditions, have been found to be entirely free from flash-arc troubles. It has, however, been demonstrated by B. S. Gossling that any tendency to flash-arcing is accentuated when valves are run in parallel on H.T. supplies of relatively large power capacity; I should therefore be interested to know whether any such discharges have so far been encountered at the station.

Mr. J. A. Cooper: On page 453 it is stated that each generator is connected directly to the associated valve filament without switchgear. Are protective devices included in the connection? If not, perhaps some statement could be made as to whether any trouble is likely to arise in the valve circuit, and, if so, as to what is likely to happen.

Referring again to page 453, it is stated that " The machines possess a self-selecting feature which operates as follows: Each generator is provided with a 2-pole contactor, also highly insulated from earth, which is energized from the exciter terminals and closes as soon as the machine is started." I should be glad if the authors would explain this arrangement more fully.

I should like to know why the designers departed from the practice of using in " C " units banks of valves in push-pull, and employed instead pairs of large valves which are individually far more costly. Finally, perhaps it would be of interest if the authors would explain in detail what is shown in Figs. 12 and 13.

The Authors' Reply to the Discussions at London, Birmingham, Manchester, Newcastle, and Glasgow.

Sir Noel Ashbridge, Mr. H. Bishop, and Mr. B. N. MacLarty (*in reply*): Colonel Angwin raises the question of the use of aerials directional both in the horizontal and vertical planes. With regard to the former, we do not consider it desirable to give a directional effect towards the north to improve the service to Scotland, since the strength given in the south-west and along the south coast is by no means more than adequate. As to directivity in the vertical plane, this is a question which has been much discussed by radio engineers all over the world during the past few years. While it is now generally admitted that for medium waves an aerial can be designed which will project a high percentage of the energy at a small angle with the horizontal plane, the difficulties become considerable when an attempt is made to apply the same principle to long waves. There is, however, in existence a design which it is claimed will achieve a similar object. This involves the use of a large number, say 6 or 8, of high masts, and a very large area of land. It is stated that this system is to be tried in Germany, but the cost is admittedly very high indeed, and it has not yet been proved that the results are in proportion to the cost.

With regard to the comparison between the power consumption in the case of series modulation and high-power modulation, it is presumed that Col. Angwin has in mind high-power class B modulation. If this is the case the figures for relative power consumption would be of the right order, although his estimate of 1d. per unit for power is about 50 per cent too high. If, however, reference is being made to class A modulation in comparison with series modulation, it will be found that there is no appreciable difference between the two from the point of view of power consumption. The class B modulation system was not adopted when the station was being designed, since it had not been proved to our satisfaction that the distortion when using this method would be sufficiently low.

Col. Angwin and several other speakers have raised the question of the reliability of mercury-arc rectifiers for the high-tension d.c. power supply. When it was decided to install mercury-arc rectifiers it was realized that there might be trouble from " back firing " with such equipments working at this voltage. Nevertheless, it was anticipated that the interruptions arising from this cause would be brief, and sufficiently infrequent not seriously to affect the service. However, on account of a certain degree of uncertainty as to the performance of these rectifiers, it was decided to use mixed plant, consisting of mercury-arc rectifiers and high-tension motor-generator sets. The object in view in attempting to use mercury-arc rectifiers was to obtain improved efficiency coupled with a considerably lower first cost. At the time of writing it cannot be said that the performance of the mercury-arc rectifiers compares with that of motor-generator sets from the point of view of reliability, but experimental work is still in progress with a view to eliminating a tendency to " back fire."

With regard to Col. Angwin's query concerning an

* Corrected for the *Journal*.

DISCUSSION ON "THE DROITWICH BROADCASTING STATION"*

FURTHER CONTRIBUTION TO THE DISCUSSION BEFORE THE INSTITUTION.

Mr. H. Chireix (France) (*communicated*): In the London discussion on this paper Mr. Shams-el-Deen inquired why the B.B.C. did not make use of the " phase modulation " system developed by the Société Française Radio-Electrique. The authors replied (see vol. 77, page 486) that they did not agree that the system is superior to or has economic advantages over that used at Droitwich. Whilst I am convinced that excellent results have been obtained at the Droitwich station from the quality point of view, and more especially as regards relative freedom from low-frequency harmonics, results quite as satisfactory are obtained with the phase-modulation system.

Table

Modulation	Low-frequeny charmonics
28 per cent	1·6 per cent
52 per cent	2·5 per cent
61 per cent	2·6 per cent
74 per cent	2·6 per cent
80 per cent	2·9 per cent
86 per cent	3·4 per cent

Apart from the Poste Parisien station, the Société Française Radio-Electrique has equipped Radio-Luxembourg with this system and more recently the French State broadcasting stations at Lille and Paris (PTT). A fidelity curve recently plotted at Lille gave the results shown in the Table.

Under the same conditions the efficiency of the last amplifying stage, measured as the ratio of the power applied to the anodes to the power collected in a water-cooled resistance representing the antenna, was over 60 per cent.

The Radio-Luxembourg station, which most closely resembles Droitwich from the point of view of power (150 kW in the antenna) and wavelength (1 304 m), operates under the following conditions:—

Antenna power on carrier	150 kW
Power taken by the valves of the last stage ..	250 kW
Power taken on carrier from the Diesel engine, all auxiliaries being included	430 kW
Average power taken during modulation ..	450 kW

These figures show a considerable advantage compared with those on page 467 (vol. 77).

The system was fully described in the November (1935) issue of the " Proceedings " of the Institute of Radio Engineers.†

EAST MIDLAND SUB-CENTRE, AT LOUGHBOROUGH, 22ND OCTOBER, 1935

Mr. A. Brookes: I should like to refer to the troubles associated with the series-modulated amplifier with the grid and filament circuits at the high-tension end of the system. Are the authors satisfied that, considering these troubles and disadvantages, the series modulation system is the best? Also, would it not have been better to have had an a.c. lighting system?

Presuming that the cooling water is in intimate contact with the valve anodes, I should like to know whether the whole cooling system for the anodes is completely insulated; or, if not, how the necessary insulation is obtained.

With regard to anode-voltage modulation, one of the main troubles appears to be that the iron-core inductances give distortion. I suggest that it might be advantageous to have a small air-gap in the iron-core circuit, as we do in telephone coils.

Regarding the master oscillator, if there had been no possibility of a change in wavelength, would not fewer difficulties have arisen had a crystal control drive been adopted instead of the valve drive?

Regarding the definition of zero volume mentioned on page 465, this seems to be purely an arbitrary standard from which the other measurements were made, and seems to be a very weak form of " zero."

With masts of the size and type described one would expect a great deal of trouble due to lightning. I should be very glad to know what safeguards are employed in order to overcome these difficulties. Is any trouble experienced due to capacitance variations of the aerial and down-feed in high winds?

With regard to the overall equivalent of the circuits between Birmingham and Droitwich, this is given (on page 446) as 20 decibels, which appears to be high. The distances stated would give this amount of degrading if 20-lb. conductors were used, whereas 40-lb. conductors are actually employed. End circuits, etc., would increase the degrading, but even so it appears high.

With regard to the earthing system, are the 72 copper wires installed as equally-spaced radii or in such a manner as to tend to minimize the directional effect of the aerial system, so as to give a better polar curve?

Mr. F. Nicholls: I have noted with particular interest that the generating plant at Droitwich is self-contained, and has no connection to the public supply mains.

* Paper by Sir NOEL ASHBRIDGE, Mr. H. BISHOP, and Mr. B. N. MACLARTY (see vol 77, p. 437).

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I understand that this is not general practice, and it would appear that the installation could have been simplified considerably had such a course been adopted.

I appreciate that the engineers responsible for the construction would have in view the possible interruption of the public supply at times of national crisis or under war conditions, but provision of a duplicate supply would appear to meet such contingencies.

Mr. F. H. Pooles: The insulators supporting the masts must be subject not only to high-frequency currents but also to a considerable crushing strain, and I should be interested to learn the details of their design. Further, have any difficulties been experienced with the porcelain couplings when the high-tension generators have been unduly stressed?

The mercury-arc rectifiers are controlled by induction regulators, although grid control is fitted. Is the large voltage range the reason for this, or was some technical difficulty experienced with grid control?

[The authors' reply to this discussion will be found on page 436.]

NORTH MIDLAND CENTRE, AT LEEDS, 29TH OCTOBER, 1935

Mr. W. Donnelly: Between 1907 and 1914 the transmitting stations erected by Marconi's Wireless Telegraph Co. were equipped with generators supplying direct current at 10 000 volts. These machines proved extremely reliable. After this period there was a lull in the demand for high-voltage direct current, and it was not until the advent of broadcasting, and, of course, the G.P.O. wireless-telephony station at Rugby, that interest revived. This period saw the development of rival methods for the production of high-voltage direct current; the mercury-arc rectifier and the hot-cathode valve appeared, and it looked as if the days of the high-voltage generator were numbered. Now, however, it appears to be the most satisfactory source of high-voltage direct current, chiefly on account of its reliability, which seems to be unequalled. It is quite true that the generator is sometimes dearer than the rectifier. I think that for 20 kV, 600 kW, the mercury-arc rectifier is the cheaper by about 25 per cent, but at lower voltages the saving disappears. The size of the mercury-arc rectifier is mainly dependent on the current. There is little difference in cost between a 10 000-volt and a 20 000-volt rectifier. It has been suggested that the hot-cathode rectifier is more economical at high voltages, particularly for low currents. In this connection it is interesting to note that generators are made for 45 kV and 150 mA which are running day in and day out on a most onerous service, namely electrical precipitation. They compete in price not only with the hot-cathode rectifier but with the oxide-film type, which one would think would be the cheapest possible system for very small currents.

I should like to have the authors' opinion on what will be the ultimate field for the various types of rectifier plant. My own view is that for voltages over 30 kV and currents over 30 amps. we may have to think again about the transvertor. The transvertor is a rectifier which gives a true d.c. wave-form, without any distortion. Immersion of the a.c. windings in oil overcomes a lot of the difficulties experienced with armatures with slotted cores. In broadcasting the problem is purely that of a.c. to d.c. conversion, and we do not meet with the trouble of having to correct the power factor to attain stable voltages. The difficulties experienced with the transvertor were purely due to this necessity for improving the wave-form when converting from direct current to alternating current, and to the attempt to turn out a machine for 100 kV, which was probably somewhat too high a voltage. Added to that there was the fact that at the time the transvertor was developed materials were not so good as they are now. Practically every failure occurred in a moulded material. To-day a lot of those problems have been solved, and more attention is paid to grading than was done in certain parts of the transvertor at that time.

The point that interests me is the future development of the requirements for broadcasting. Is it not a fact that the power which may be put into an aerial is, and will remain, limited by international conventions? Is there any prospect in this country of ranges greater than that given by Droitwich being required? In other words, are our power requirements going to be forced up? If not, then we may still have to consider whether we shall want higher voltages and lower currents, or lower voltages and higher currents. I should like to have the authors' opinion on this point.

One of the interesting points mentioned in the paper is the use of a special winding on the alternator in order to avoid the effect of harmonics due to rectifiers. This difficulty will no doubt also have to be met in other fields where the rectifier is the main load on the system.

With regard to the device employed for cutting off the supply from the valve, it seems extraordinarily drastic to short-circuit a 600-kW 20-kV machine. In practice, however, it is not so serious. Practically all the breakdowns I have met with on high-voltage direct-current systems have been due not to short-circuits, but to attempting to break short-circuits. The breakdown is almost always due to armature-coil inductance causing a breakdown between commutator bars or in the coil itself. It is the instantaneous voltage-rise set up on opening the circuit which usually does the damage. Have the authors ever had any trouble due to the short-circuit device failing to take over the current from the valve? Apparently the occurrence of a flash-arc in a valve is equivalent to a dead short-circuit. To be effective, the second short-circuit must be better than the first; has any trouble been experienced due to this? If so, would it not be possible to incorporate in the short-circuit device an additional arrangement which, when the switch closed, would insert a resistance in the load circuit just before the short-circuit was applied?

Prof. E. L. E. Wheatcroft: One of the most important parts of the paper deals with the question of generation of high-voltage direct current for the output valves, and naturally the greatest point of interest is the relative success of the high-voltage generators and the mercury-arc rectifiers. Since the paper was written the station

I understand that this is not general practice, and it would appear that the installation could have been simplified considerably had such a course been adopted.

I appreciate that the engineers responsible for the construction would have in view the possible interruption of the public supply at times of national crisis or under war conditions, but provision of a duplicate supply would appear to meet such contingencies.

Mr. F. H. Pooles: The insulators supporting the masts must be subject not only to high-frequency currents but also to a considerable crushing strain, and I should be interested to learn the details of their design. Further, have any difficulties been experienced with the porcelain couplings when the high-tension generators have been unduly stressed?

The mercury-arc rectifiers are controlled by induction regulators, although grid control is fitted. Is the large voltage range the reason for this, or was some technical difficulty experienced with grid control?

[The authors' reply to this discussion will be found on page 436.]

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My next question relates to radio transmission and refers to the overall frequency characteristic which forms an important part of the later sections of the paper. In Fig. 25 the authors say that had the valves been connected directly to the aerial there would have been considerable distortion. The ratio of impedance from 200 to 260 kilocycles is, as I read the figure, not more than 2 to 1—a matter of only 3 decibels. It therefore seems to me that the extra quality is of little value from the point of view of the receiver and is not worth the extra equipment which has been put in.

Mr. J. F. M. Mellor: It will be seen from Fig. 4 that there are several property boundaries and a public road within 300 yards of the Droitwich aerial; in order to prevent large currents being induced in neighbouring conductors, or metalwork being raised to a dangerous potential above earth, do steps have to be taken to ensure that the boundaries are not made with unearthed wire fences?

Mr. H. S. Ingleby: We in Leeds were rather disappointed when the Droitwich station opened, as we had expected it would give us stronger signals. Table 3 and Fig. 37 show us why it did not. It is rather interesting to notice that although Portsmouth, London, and Leeds, are all about 100 miles distant from Droitwich, there is a wide difference between the field strengths at these places (London 17·5, Leeds 10·3, Portsmouth 16·2 mV per metre). I think the low value at Leeds is explained as due to the Pennine Range. How do the field strengths of these three areas compare in the case of the medium-wave station, where a reflector is employed? Do we get, relatively, a better percentage from the medium-wave than from the long-wave station?

[The authors' reply to this discussion will be found on page 436.]

MERSEY AND NORTH WALES (LIVERPOOL) CENTRE, AT LIVERPOOL, 4TH NOVEMBER, 1935

Prof. E. W. Marchant: There is one point in particular to which I should like to refer, and that is the use of Diesel-engine sets at the station. Use might have been made of the national supply from the grid which is now available; but it is obvious that a broadcasting station should maintain a service under all contingencies, and the Diesel sets ensure that the broadcasting service will be maintained, whatever may happen to the rest of the country.

In the oscillograms of Fig. 7 (Plate 1) some of the voltage waves are far removed from the true sine-wave form, but this, I think, is partly due to the fact that the rectifiers have been supplied from a comparatively small generating set. If the power for the rectifiers were taken from a large set or from the grid, the distortion would not be anything like so bad.

Another interesting point in connection with this paper is the design and working of the high-frequency circuits. Unless one has had practical experience of this sort of work one can have no idea of the difficulties that are involved. For one thing, the insulating materials behave in a very different fashion when they are subjected to high-frequency voltages—say, from 500 to 1 000 kilocycles per sec.—instead of the ordinary 50-cycle supply. The breakdown voltage is much lower, and the insulating material tends to get very hot. One of the difficulties we have met with is the instability of the oscillating circuit under varying load. I expect the authors are familiar with the instability that occurs with an oscillating valve the oscillations in which are produced by having the grid inductively coupled to the anode circuit; in our case we have found it necessary to use a driving valve on the grid of the oscillator in order to ensure complete stability at varying outputs.

The curve in Fig. 37, which gives the frequency characteristic over a range from 50 to 6 000 cycles for the complete circuit, is a very good one, in view of the large number of transformations that the speech current has to go through before the final record at the checking receiver is obtained. Not only is it necessary to have an accurately modulated high-frequency current in the aerial, but the aerial itself may produce distortion, i.e. the waves given out by the aerial may not preserve a proper ratio between the magnitudes of the fundamental and the harmonic of the speech currents. The fact that the aerial itself may introduce distortion is very interesting.

I should like to refer to Fig. 25, which gives the impedance of the Droitwich aerial at various frequencies. If the impedance at a point that corresponds to a wavelength of 1 500 m (frequency 200 kc) is taken, and a range of 6 000 cycles (the frequency range for good modulation) is considered, the difference between the values of the impedance at the two ends of the scale is appreciable: at 206 kc the impedance is about 23 ohms and at 194 kc it is about 18 ohms. I should like to ask whether any attempt has been made to compensate for this at any stage of the transformation. It is possible, of course, to over-modulate at one stage to make up for these differences.

The word "transducer" is new to me, but the French word *transducteur* has a similar meaning. Is the word "transducer" generally used in connection with broadcasting stations, or is it limited in its application?

Mr. F. Mercer: With reference to the telephone circuits rented from the British Post Office (page 446), it is stated that the nominal cut-off frequency is 8 400 cycles and that with suitable equalizing circuits a flat response is obtained between 50 and 7 000 cycles. From the data given, the calculated cut-off frequency appears to be 7 400 and not 8 400 cycles, as stated; a cut-off of 7 400 cycles seems too low for the transmission of a frequency of 7 000 cycles. The spacing is given as 1·36 miles, whereas a normal Post Office spacing is 2 000 yards (1·136 miles). Possibly the authors' figure is incorrect.

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being highly efficient, but on the other hand it appears to be open to two objections: first, that it is spread out over an exceedingly large area, so that the expense of installing is outweighed by the cost of the land; and secondly, that operations such as building, ploughing, or trenching, are likely to interfere with it, and in course of time cause it to become less efficient. Have the authors considered a more straightforward system such as a line of conducting rods or pipes placed at uniform distances apart, penetrating well into the subsoil and linked with copper conductors of suitable cross-sectional area?

Mr. C. Rhodes: The more interesting features of the Droitwich station are: (1) The series modulation system. (2) The transducer. (3) The mercury-arc rectifiers.

With regard to (1), this appears to present a very practical solution to the difficulties usually encountered in long-wave transmitters. It avoids the distortion associated with choke or transformer modulation, and, being located in the penultimate stage, does not require a number of elaborate inter-stage coupling circuits. The final amplifier appears to be run as a semi Class B stage, and I should be glad to know whether this stage is responsible for the bulk of the 4 per cent distortion referred to in the paper.

Turning to feature (2), it is very interesting to a telephone engineer to see filter network theory being applied to an aerial feeder line. Table 4 and Fig. 38 testify to the correct functioning of the transducer, which apparently reduces the harmonic output to a very small value and corrects the frequency/response characteristic. I understand that, in America, modulation up to 15 000 cycles is accomplished by some of the newer stations. The restriction of the modulation to 7 000 cycles in the B.B.C. stations is, as the authors point out, due to the design of the Post Office cables and the aerial-coupling arrangements. It would be fairly easy, although costly, to raise the limit of the cables very considerably by using loading coils of smaller inductance placed closer together, with suitable corrective networks at the repeater stations. A 7 000-cycle frequency range seems rather inadequate for the high-fidelity receiver of the future, and it would be interesting to know whether a transducer can be designed to work up to 10 000 or 15 000 cycles, or whether long-wave stations are doomed to a restricted frequency-range. Is the line equalizer, shown in Fig. 33, inserted at every amplifying point in the cable, or only at Droitwich?

Finally, dealing with feature (3), it is surprising that such a simple circuit as that shown in Fig. 24 is capable of smoothing the relatively bad wave-form of the mercury-arc rectifiers. Also, one would think that impedance values of ($30\ \mu F + 25\ \Omega$) and ($30\ \mu F + 50\ \Omega$), would be high enough to have an adverse effect on the low-frequency response of the transmitter. Fig. 38, however, shows that the actual loss is very small.

There is a minor error in Fig. 23; the description "DEM3" applied to the first valve should read "DET3."

Mr. J. H. Phillips: I should like to ask some questions about the filter and feeder system. I cannot understand why the output filter system is arranged to form a balanced network; surely an unbalanced filter, in conjunction with a concentric feeder to the aerial, would have been much simpler to construct. The concentric feeder would probably further simplify the filter network, as the harmonic radiation would be lower than with an open-type feeder line.

The use of a sliding contact for the aerial tuning inductance is interesting. I would like to know why this procedure was adopted in preference to a device giving an adjustment of mutual coupling.

In the description of the main amplifier it is stated that the use of permanently sealed valves of the largest size made was essential. I should have thought that to have split up the main amplifier into two or more units using valves of smaller power would have been a more reliable arrangement. The modulated amplifier could have been treated in the same way. Failure of any one of the units would not then cause a complete breakdown of the station. With suitable automatic equipment to cut out the faulty unit, the service could be continued at reduced power or modulation after a very short break.

Whilst the precautions at Droitwich seem adequate to deal with any emergency, the question of delay time does not appear to have been dealt with. I should like to have seen greater use made of fully automatic equipment to take care of breakdown conditions.

In the use of high-power valves we appear to be in line with Continental practice. At Radio Vienna the output of 100 kW is handled by two valves, each of 300 kW nominal rating. These have indirectly-heated cathodes and are run from a 50-cycle supply.

The claims made for the method of modulation adopted at Droitwich call for some investigation. It is interesting to compare this method with the system in use at the Cincinnati station (Ohio, U.S.A.), where a power of 350 kW is used for 100 per cent modulation. The speech amplifier is transformer-coupled throughout and has an overall gain of 28 000 000.

The question of the difficulties of design of iron-core chokes and transformers to handle large powers without introducing serious distortion has been raised. At Cincinnati the speech-amplifier output is handled by two oil-immersed transformers each of 180 kVA rating at 30–10 000 cycles, and it is claimed that over this frequency range the output does not deviate by more than 2 db from the value at 1 000 cycles. The physical dimensions of these transformers are of interest; they weigh about 19 tons each and are 11 ft. high overall. The direct-current component of the main-amplifier output is passed through a choke rather than through the secondary windings of the transformers. This choke weighs 12 tons. Whilst I do not know what claims are made for this system in regard to the reproduction of transient wave-forms, from the listener's point of view the better reproduction at the high-frequency end more than compensates for any discrepancies that may exist.

There are times when the quality of the Droitwich transmission is definitely inferior to the average quality of transmission from that station. It is difficult to believe that this can be due to landline or studio troubles, as a similar criticism does not apply to stations on the medium wave-band handling the same programme. I should like to have the authors' explanation of this, and also of the fading which occurs.

Mr. T. R. Lupton: The authors stress the fact that large transmitting valves of the CAT type are very costly; is the filament of this type of valve renewable? Presumably the filament is the source of failure of the valve. Also, since a breakdown affects so many listeners, are routine tests carried out to ensure that each valve is retaining its normal characteristics? It is possible that this latter feature is sufficiently covered by switchboard instruments.

It is pleasing to find that the authors use the diode type of modulation meter, because this is the type which we have found most useful in the Ferranti laboratories. There are many arrangements which can be used as modulation meters, but a modern type of radio receiver lends itself well to this purpose. The high-frequency component is measured by inserting a microammeter in series with the diode load, which is usually of the order of 0·5 megohm, thus giving the desired linearity to the rectifier system; while the low-frequency component is amplified in the usual way and can be measured by means of a rectifier voltmeter across the secondary of the output transformer. Naturally it is necessary to calibrate the low-frequency amplifier, and one does not normally use the high-frequency amplifying stages. This method of utilizing a radio receiver is very useful because of the ease of availability of the latter.

It may be interesting to power engineers to emphasize the achievement indicated by the statement that the amount of 2nd harmonic in the aerial circuit is only 1/1970 of the fundamental. If, as is usual, this statement is made in terms of voltages, then when 150 kW is being radiated from the aerial at the fundamental frequency, only 0·04 watt is radiated at the 2nd-harmonic frequency, i.e. the fundamental power is $3 \cdot 88 \times 10^6$ times the 2nd-harmonic power.

I would criticize Fig. 38 since it gives an overall frequency/response curve which includes the response of the checking receiver at Broadcasting House. The curve, if intended to give the transmitter fidelity, would be more illuminating if it did not include the check receiver; while if it is intended to indicate the fidelity to be expected from the complete broadcasting chain, then the loud-speaker output should be given, not the receiver output.

Since the porcelain coupling shown in Fig. 17 is very unusual, it would be interesting to know the safety factor against shear in this coupling when the machine is started.

Can the authors state to what depth it is desirable to have good subsoil under the aerial? One would expect good earth conductivity to be an advantage; poor conductivity in one direction, for example, would possibly upset the polar distribution of radiation.

Finally, has any effect on animal life in the neighbourhood of large radio-frequency fields been noticed, e.g. are the engineers in any way affected by these fields?

Mr. C. R. Bolton: It is noted that American whitewood has been used in the construction of the formers for the coupling transformers, and it would be interesting to have some information as to the dielectric properties of this material at high frequencies. A few years ago, when an insulating material was needed for high-frequency work, whitewood was tried with disappointing results as regards dielectric loss in relation to other materials. Ultimately the wood of the tulip-tree (*Liriodendron tulipifera*) was used.

It would be of interest to know the mechanical construction of the stays for the 700-ft. masts. It is understood that at Rugby the stays consist of parallel wires bunched together without spiralling: this construction was adopted so as to obtain the minimum amount of stretch for a given load, and involved laying-up the stays on site, as such stays will not bend easily, and cannot be wound on drums for transit. What is the latest practice in this connection?

Mr. G. Avery: The authors refer to backfiring having been experienced with the rectifiers. I should be glad to learn whether this trouble has since been overcome.

Mr. J. O. Knowles: I should like to comment on the tidy and clean layout of the Droitwich station. In layouts designed by mechanical engineers the electrical gear often appears to have been added as an afterthought. Similarly, architects do not always consider the electrical layout at a sufficiently early stage. It is therefore very encouraging to electrical engineers to find, in a station where the electrical gear is a prime consideration, a layout worthy of modern electrical engineering.

THE AUTHORS' REPLY TO THE DISCUSSIONS AT LOUGHBOROUGH, LEEDS, AND LIVERPOOL

Sir Noel Ashbridge and **Messrs. H. Bishop** and **B. N. MacLarty** (*in reply*):

We thank Mr. Chireix for his communication and have noted with interest the operating conditions of Radio-Luxembourg.

Loughborough.

In reply to Mr. Brookes, we are of the opinion that the advantages of the series modulation system outweigh the difficulties associated with the electromechanical design of the circuits. The type of circuit adopted and the mechanical design of the various components have proved to be entirely satisfactory.

With regard to the advantages to be obtained by the use of alternating current for heating the filaments of the modulated amplifier valves, the possibility of spurious modulation with this arrangement outweighs the advantages of simplicity of equipment.

The valve-cooling system is not insulated, but the valve-anode water jackets are insulated by coils of rubber hose, as described in the paper.

It is agreed that a crystal-controlled oscillator would achieve a greater constancy of carrier frequency than the valve oscillator. However, the reasons for the adoption of the latter are given on page 459 of the paper.

The mast insulators and associated circuits are protected from the effects of lightning discharges by horn gaps. No trouble due to variation of aerial constants in high winds has been experienced. Considerable

the purpose of constructing a coil to carry 50 amperes which has a temperature coefficient of only a few parts in a million. In an actual frequency-drift run on a 1-kW transmitter, it was found that the drift was only one-tenth that produced with an ordinary helical coil.

The test results given in the paper were obtained with a Hartley circuit of small power (about 3 watts), but some of the coils have been developed for large power and have been tested under conditions similar to those which exist in an actual transmitting installation.

With reference to Mr. Griffiths's communication, I note that the expectations of the manufacturers in respect of coils M and N are considerably less than I had assumed from a perusal of their published information. It is quite clearly stated in the Introduction* to the paper that the present discussion " is restricted to the form of coil which is in current use in practically all short-wave applications, namely, an open-type helical coil of a few turns wound on a former or a coil in which the turns are sufficiently rigid to be self-supporting." I am pleased to learn that Mr. Griffiths finds that exceptional workmanship is required to produce condensers having low temperature-coefficients of capacitance, and I thank him for the interesting figures which he gives for the performance of some precision condensers.

* Vol. 77, p 703.

DISCUSSION ON "THE DROITWICH BROADCASTING STATION"*

Mr. S. R. Kantebet (India) (*communicated*): Dealing first with the question of site selection, the importance of this, so far as the ultimate success of a modern high-power broadcasting station is concerned, cannot be overstressed. From the paper, site selection appears to have been done by (*a*) boring to ascertain the nature of soil strata under the station, and (*b*) actual field-strength measurement. I should like to know why it was found necessary to bore to a depth of 300 ft., as from the radiation point of view it would appear needless to go so deep. Radio-frequency currents do not penetrate more than a mere fraction of this depth into the ground; and in fact, as the main earth wires are sunk only 9 in. in the soil, the amount of current beyond this depth will be negligible. As for foundation strength, the nature of the soil beyond a depth of 10–15 ft. would not be of much importance, since the mast load—including stays and the concrete base block—would not exceed 1·25 tons per sq. ft., which is not much more than the loading due to an average 6-story building. Has this deep boring been of help either from the radiation or from the mechanical-strength point of view?

Turning to the subject of the earth system, a system of 72 copper wires of No. 16 S.W.G. radiating from the aerial base and laid in furrows 9 in. deep is doubtless a simple and economic structure. May I ask whether the earth system is not too near ground level to be unaffected by daily variations in temperature and soil humidity. It appears to be a compromise between a well-insulated counterpoise and a deep-laid earth net, well beyond the reach of temperature and moisture variations. I should be glad to know whether any earth-resistance measurements have been made over a period long enough to cover both daily and seasonal variations in soil constants. These figures should prove instructive. We in India have constant difficulty in finding suitable earth connections, both for transmission and for direction-finding work.

As regards the aerial-transformer house, the aerial coupling gear is in duplicate, and the spare set can be brought into circuit without delay by means of isolator switches. From Fig. 4, the transformer house appears about 600–700 ft. from the transmitter building. Is the operation of change-over switches carried out by some system of remote control, or has the operator to run to the transformer house and effect the change?

The use of aerial systems for directional effects on medium waves is fast coming into use, and it seems practicable to design for any polar curve—from a perfect circle, through a cardioid, to an elongated " D," and finally to a flat beam. As an interesting instance may be quoted the polar curve of the 50-kW station WOR at Cartaret, New Jersey. The station is 17 miles south-west of New York, on the line New York—Philadelphia. These two are thickly-populated modern industrial centres with high noise-level. At right angles to the above line are smaller towns of importance and, still farther away, quiet rural areas. The aerial system gives a field equivalent to a 120-kW radiation in the direction New York–Philadelphia and to one of only 5 kW in the direction at right angles. Have any special devices been fitted to maintain the requisite phase relationship between the aerial and the reflector at Droitwich? Some further details of the reflector would be appreciated.

It would be interesting to know whether the open-wire feeder, being exposed to the intense radiation field of the aerial, produces radio-frequency feed-back; and in particular whether it affects the polar curve of the aerial itself. Does the polar curve given in Fig. 36 take into account the effect of the long overhead feeder?

It is a big step forward to be able to predict the

* Paper by SIR NOEL ASHBRIDGE, Mr. H. BISHOP and Mr. B. N. MACLARTY (see vol. 77, p. 437, and vol. 78, p. 432).

characteristics of projected aerials of great size from tests on equivalent models. It is not clear from the paper what actual tests were carried out on the models; were they transmission or reception tests (I notice that experiments were carried out at Tatsfield receiving station)? What were the modulation band widths employed on the $\frac{1}{7}$ and $\frac{1}{10}$ scale experiments? Can the test-results obtained on the model be assumed *in toto* for the real aerial, or has any correction factor to be applied? Information on all these points would greatly assist in the design of aerials for high-power stations.

Dealing with the subject of filament heating, the filament currents of cooled-anode valves drawing several hundred amperes can be switched on and off only very slowly, lest the sudden rush of current, or its drop, should produce local mechanical stresses on the filament. In fact, this operation should take at least 1–2 minutes. Since at Droitwich each CAT 14 valve has its own supply generator, connected direct on to the filament without

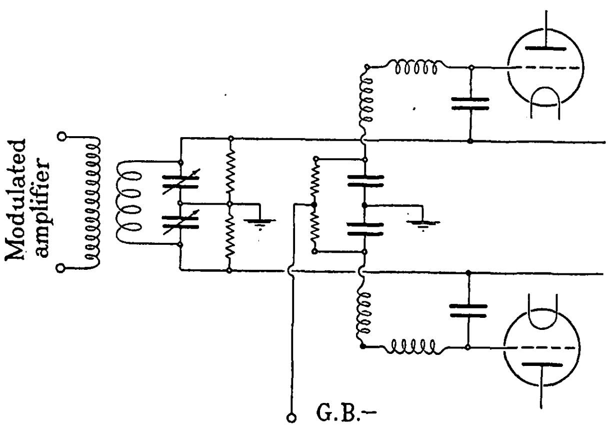

Fig. A

any intermediate switchgear, has any special delay mechanism been fitted to prevent sudden increase or decrease of current on starting or stopping of the motor-generator?

Regarding the filament of the modulator valve, it is not understood why a simple high-insulation transformer was not preferred to the cumbrous insulated motor-generator set.

In the main power amplifier, with four CAT 14 valves working in parallel push-pull, what provision is there to show that the high-frequency load is shared equally by all the four working valves? In Fig. 19, the way of leading grid negative bias to the grid terminals is not clear. Should not the connection be as shown in Fig. A? In the authors' diagram the bias lead appears to be short-circuiting the bias resistance.

Sir Noel Ashbridge, Mr. H. Bishop, and **Mr. B. N. MacLarty** (*in reply*): Mr. Kantebet does not appear to have appreciated the reasons for making a trial bore on the site to a depth of 300 ft. This work had no relation to investigations regarding the conductivity of the soil in the neighbourhood of the station, but was intended to ensure that the possibility of subsidence did not exist. As mentioned in the paper, serious subsidences have occurred in the vicinity of Droitwich owing to the existence of extensive salt deposits. Mr. Kantebet's observations regarding the depth of radio-frequency current penetration into the soil, and the loading on the foundations of the buildings and mast, are therefore irrelevant.

In reply to the question as to whether the type of earth system used at this station is affected by variations in temperature and soil humidity, it can be stated that no variations have been observed due to excessive dryness. This is probably due to the fact that the soil under the aerial is covered with thick grass, which of course tends to conserve the moisture. The wide variations in resistance of this type of earth system observed by Mr. Kantebet may be due to the different conditions which may exist in India. It may be of interest to mention that the only weather condition which causes variation of earth resistance is prolonged frost, when the ground beneath the aerial may become frozen to the depth of a few inches. This condition is of infrequent occurrence in this country and can be compensated for by slight adjustment of the aerial tuning circuits.

When criticizing the adoption of manual switchgear for bringing into use the spare aerial tuning equipment Mr. Kantebet has lost sight of the fact that the reason for breakdown must be investigated, and this in any case requires the presence of an engineer in the aerial-transformer house. Further, it is necessary in any case to inspect the aerial tuning equipment after a breakdown to ensure that a flashover has not occurred and caused a fire. If this point be taken into consideration it will be appreciated that the use of automatic switchgear would offer little advantage.

We agree that directional aerials are now being used extensively for the purpose of adjusting the polar diagram of the aerials of medium-wave broadcasting transmitters. In the directional aerial system cited in the paper a latticed network has been incorporated in the aerial coupling circuits in order to give the requisite phase-difference of $\pi/2$ between the aerial and reflector. The mutual impedance between the balanced transmission lines and the radiating wires is negligible; the polar curve (Fig. 36) is a measured curve and includes any small effect which the presence of the transmission line might cause.

The tests carried out upon the model aerial system at Tatsfield consisted of measurements of driving-point impedance and of the received field round the aerials when driven. The tests were carried out with unmodulated signals, since the band width of the aerials was readily calculated from the impedance characteristics. The principal correction necessary in order to predict the performance of the real aerial, as compared with that of the model, is the difference in conductivity of the earth at frequencies employed with the model and the real aerial respectively. This presents little difficulty at the short distances involved in the measurements.

With regard to the question as to whether delay mechanism has been fitted to prevent sudden increase or decrease of current in the filaments of large valves at Droitwich, suitable interlocks have been provided which prevent the starting of the motor-generators unless the field regulator is set at the minimum-voltage position.

Further, the field regulators are motor-operated, the motor speed and gearing being designed to produce a relatively slow movement in the regulator. It is therefore impossible to increase the filament current at a rate which may be dangerous.

With regard to the danger of sudden interruption of current, this point is covered by the fact that the valve filament is permanently connected to the armature of the generator, without intermediate switchgear. The rate of decrement of current is therefore governed by the rate of collapse of the generator field. It should be remembered that, owing to the thermal characteristics of the filament, rapid application of voltage is far more dangerous than rapid interruption.

With regard to the lighting of the filaments of the modulated amplifiers, it appears that Mr. Kantebet has fallen into a common error on this point. Although at first sight it appears that a highly insulated transformer would be a more simple and economical method of lighting these filaments, when the matter is fully investigated on a practical design basis it is found that there is little to be said for either system; and, taking into account the fact that the motor-generator eliminates all danger of ripple on the carrier, it may be said to possess the advantage. It is well known that to reduce the carrier hum due to a.c. lighting even to a reasonable limit, it is necessary to use a number of modulators heated from a polyphase system with Scott-connected transformers.

It is necessary also to provide induction regulators capable of regulation to zero voltage, and capable of extremely fine regulation around the working voltage. The transformer feeding the heating current to the valves must be of very low capacity, which involves special design and precludes the possibility of using oil for cooling or insulation. The foregoing indicates bulky and expensive plant, for which spares must be provided.

The motor-generators which were installed at Droitwich have proved to be entirely satisfactory, and the porcelain couplings have not shown sign of failure during the first 18 months of working. Difficulty is not experienced in obtaining equalization of anode d.c. input and high-frequency output between the four CAT 14 valves. This is due to the accuracy with which the valves are manufactured, their inherent characteristics, and the fact that they are operated as Class C amplifiers.

We note that Mr. Kantebet questions the accuracy of Fig. 19. The method of connection shown is correct. The resistance shunting the grid bias is the grid-bias generator loading resistance, which is used to swamp low-frequency pulses of grid current that would otherwise flow through the grid-bias generator armature and produce variation in grid-bias voltage in sympathy with the modulation.